Temporal and Spatial Characteristics of the Diatom *Ditylum Brightwellii* in the Western Isles Region of the Bay of Fundy

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by

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ABSTRACT

Martin, J.L., Hastey, C.D., LeGresley, M.M., and Page, F.H. 2007. Temporal and spatial characteristics of the diatom *Ditylum brightwellii* in the Western Isles region of the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 2779: iv + 22 p.

The abundance of the diatom *Ditylum brightwellii* has been monitored at five locations in the Bay of Fundy, eastern Canada, at weekly to monthly intervals since 1987. *D. brightwellii* was observed each year, cell densities were less than 36 000 cells•L^{-1}during all years except 2003 when numbers as high as 1.86 x 10^5 cells•L^{-1} were observed. The date for the first appearance of *D. brightwellii* in a given year was inter-annually variable and ranged from late January to early March and tended to be latest in the offshore. Maximum concentrations occurred from July to November with the median day of the maximum cell abundance in September. The stations outside Passamaquoddy Bay had the highest concentrations, suggesting that this region was more conducive to higher cell densities and blooms of *D. brightwellii*. The annual maximum concentration varied among stations and between years by up to five orders of magnitude. The median maximum value (in cells•L^{-1}) was 2680 (Lime Kiln Bay, a sheltered bay), 4624 (Deadmans Harbour, a bay exposed to the offshore), 5120 (offshore near the Wolves Islands), 200 (Brandy Cove, an estuarine site) and 4297 (mid Passamaquoddy Bay). The annual duration of the presence of *D. brightwellii* ranged from January to December (365 d) and had a mean of 128.5 d, whereas the duration of the bloom containing the annual maximum concentration varied from 106-176 d. The characteristics of the annual *D. brightwellii* blooms varied between years and stations with the number of blooms or high abundance periods varying from one to two per year.

RÉSUMÉ

Martin, J. L., Hastey, C. D., LeGresley, M. M., and Page, F.H. 2007. Temporal and spatial characteristics of the diatom *Ditylum brightwellii* in the Western Isles region of the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 2779: iv + 22 p.

Depuis 1987, l'abondance de la diatomée *Ditylum brightwellii* a été suivie à cinq sites situés dans la baie de Fundy, est du Canada soit à chaque mois ou à chaque semaine. *D. brightwellii* a été observée chaque année, atteignant, durant cette période, une concentration annuelle de moins de 36 000 cellules·L^{-1} sauf en 2003 où on a observé 1.86 X 10^5 cellules·L^{-1}. La date de la première observation de l'année de *D. brightwellii* était variable entre années, étalait de janvier à mars et avait tendance d'être plus tard au large. Les concentrations maximales prenaient place entre juillet et novembre avec la journée médiane du dénombrement maximum en septembre. Les stations à l'extérieur de la baie de Passamaquoddy possédaient les concentrations les plus élevées suggérant que cette région est plus favorable aux proliférations intenses de *D. brightwellii*. La concentration maximale annuelle variait entre stations et aussi entre années par cinq ordres de grandeur. La valeur médiane maximale en cellules·L^{-1} était 2 680 (baie Lime Kiln, une baie abritée), 4 624 (Deadmans Harbour, une baie influencée par les eaux du large), 5 120 (station au large des îles Wolves), 200 (Brandy Cove, station estuaire) et 4 297 (mi-baie Passamaquoddy). La durée annuelle de la présence de *D. brightwellii* s'étendait de janvier à décembre (365 j) en moyenne 128.5 j, tandis que la durée de l'efflorescence ayant la plus grande

concentration annuelle variait de 106-176 j. Les caractéristiques des efflorescences annuelles de *D. brightwellii* diffèrent entre années et entre stations et varient d'une à deux proliférations par année.

INTRODUCTION

Although the majority of phytoplankton species occur in the environment without causing adverse effects, there are a few that are known to cause harm. When these harmful algal blooms (HABs) occur in areas where Atlantic salmon (*Salmo salar*) farming is conducted, the health of the caged salmon can be compromised. Farmed fish are particularly vulnerable to harmful phytoplankton blooms because they do not have the luxury of being able to swim away to avoid blooms, and heavy mortality can occur within hours. The salmonid mariculture industry in southwest New Brunswick consists of more than 90 active farms which could potentially be impacted by HABs.

Impacts to fisheries from HABs have been observed in various regions of the world (White 1980; Anderson et al. 2001; Landsberg 2002; Kim et al. 2004; Doucette et al. 2006), and particularly to salmon in regions such as: Atlantic Canada - Bay of Fundy: *Alexandrium fundyense*, and *Mesodinium rubrum* (Martin et al. 2001a, 2006a), Nova Scotia: *Alexandrium tamarense* (Cembella et al. 2002); Faroe Islands – *Alexandrium* (formerly *Gonyaulax*) *excavata* (Mortensen 1985); Northwest Pacific - *Chaetoceros convolutus*, *Chaetoceros concavicornis* and *Corethron* sp. (Gaines and Taylor 1986; Rensel et al. 1989; Speare and Ferguson 1989; Horner et al. 1990, 1997; Albright et. al.1993; Rensel 1993); Europe - *Gyrodinium aureolum* (Dahl and Tangen 1990, 1993; Romdhane et al. 1998), Chile - *Leptocylindrus minimus* (Clément and Lembeye 1993).

HABs have been known to affect fish through either of the following methods: neurotoxins, gill irritation/damage (mechanically or through the production of hemolytic substances) or asphyxiation (oxygen depletion). Farmed fish are particularly vulnerable to harmful phytoplankton blooms. The result may be mortality or stress in both smolts and market size salmon and loss of growth during a severe bloom event. These effects have caused millions of dollars of lost revenue to the affected salmon farmers and insurance companies are interested in knowing what farmers are doing to mitigate potential phytoplankton related losses. In cases where there is an anticipation of a problem, market size fish could be harvested, feeding could be reduced or the introduction of fall smolts into cages may need to be delayed due to sensitivity to phytoplankton blooms.

Salmon operations in the southwestern New Brunswick region of the Bay of Fundy have been impacted by HABs several times within the past decade. Those farms located within the Passamaquoddy and Bocabec Bay areas have been impacted more so than those elsewhere. Although HABs occur less frequently to farms outside Passamaquoddy Bay, blooms only occurred in the Grand Manan area in 2003 and caused severe economic losses at several farms in eastern Grand Manan. In 2004, blooms occurred in the region between Letang and Seeleys Cove, affecting salmon farms in that area as well (Fig. 1).

A phytoplankton monitoring program was initiated in the Western Isles region of the Bay of Fundy in 1987 due to growing concerns that the incidents involving HABs seemed to be increasing in intensity, frequency and geographic distribution throughout the world (Anderson 1989; Smayda 1990; Hallegraeff 1993, 1995). The purposes of the phytoplankton study when it was initiated were: to establish baseline data on phytoplankton populations in the lower Bay of

Fundy, since little detailed work had been published since studies by Gran and Braarud (1935); to identify harmful algal species that could potentially cause harm to the aquaculture industry; to provide an early warning to the aquaculture industries by sorting and identifying samples soon after collection; and to determine patterns and trends in phytoplankton populations. Another purpose of the study was to determine whether there were environmental changes, such as changing trends in phytoplankton populations as a result of the salmon industry. Incidences of fish mortalities, especially those held captive in net pens, had also been increasing in other regions of the world. Some of these increases can be attributed to increased awareness, both in the scientific and public communities, as well as the increased use of inshore coastal waters for aquaculture, tourism and other activities.

It is well known that phytoplankton blooms are notoriously difficult to predict. Scientists in various parts of the world have been working on this for decades with little success to date. Two decades of monitoring phytoplankton within the southwestern New Brunswick area of the Bay of Fundy have indicated that the general seasonal timing of the blooms of some species is quite consistent and hence predictable to this extent. Some initial statistical analyses have indicated that sophisticated time series analysis techniques have potential for forecasting of phytoplankton abundance.

A research program was funded under the Department of Fisheries and Oceans (DFO) Aquaculture Collaborative Research Development Program (ACRDP) to study data analysis strategies to provide information concerning (Chang et al. 2005; 2007):

1) the temporal and spatial scales of variability in the concentration of potentially harmful phytoplankton species;
2) the effectiveness of sampling and data analyses approaches for detecting the presence of potentially harmful phytoplankton species; and
3) the effectiveness of the sampling and data analyses approaches for detecting and projecting a temporal trend in the abundance of a harmful algal species.

This manuscripts is part of a series dealing with: determining temporal and spatial characteristics of particular blooms of harmful algae in the southwestern New Brunswick area from existing phytoplankton monitoring data since 1987; evaluating the statistical potential of these time series to give an early indication of a pending HAB; and determining the similarity between time series of phytoplankton collected at individual locations. Although a number of species of phytoplankton were selected from the dataset for analyses, this particular paper focuses on the diatom *Ditylum brightwellii*. A total of 10 species are being addressed as part of the project and include species that have been suggested to have caused problems with salmon in either the Bay of Fundy or species observed in the Bay of Fundy that have been implicated in fish problems elsewhere in the world, such as *Eucampia zodiacus*, *D. brightwellii*, *M. rubrum*, *Chaetoceros socialis*, *C. concavicornis*, *C. convolutus*, *Corethron criophilum*, *L. minimus*, *A. fundyense* and *Pseudo-nitzschia* spp. Results for *A. fundyense* have been published previously (Page et al. 2004, 2005, 2006) As part of this series, reports on *E. zodiacus* and *M. rubrum* have been completed (Martin et al. 2007a, 2007b).

D. brightwellii (West) Grunow (Fig. 2) is a diatom that appears to be cosmopolitan, except in polar waters (Horner 2002). Cells are 80-130 µm long and 25-100 µm in diameter. It generally occurs singly but can be in short chains (or occasionally long chains). It is free-living, rectangular from the girdle view with a single spine arising from the center of each valve (Round et al. 1990).

Although it has not been documented to have caused problems with aquaculture operations anywhere in the world, *D. brightwellii* was observed at high concentrations during an *A. fundyense* bloom when salmon mortalities were observed in the Bay of Fundy (Martin et al. 2006a). *D. brightwellii* has been documented to have had a negative effect to the copepod, *Calanus pacificus*, where the percent hatching success for eggs was zero when exposed to high concentrations of *D. brightwellii* (Ban et al. 1997).

MATERIALS AND METHODS

Sampling was initiated in 1987 at Lime Kiln Bay (Station 3 – Letang estuary where a number of aquaculture sites are located) and at the following three stations in 1988: Brandy Cove (Station 17 – a brackish site influenced by the Saint Croix River estuary), Deadmans Harbour (Station 15 – an open bay with offshore influence), and the Wolves Islands (Station16 – an offshore indicator site). An extra sampling site (Station 25) was added in mid-Passamaquoddy Bay in 1999 following the observation that Brandy Cove was not a good indicator site for cell densities of algal blooms within Passamaquoddy Bay (Fig. 1).

Sampling was conducted aboard the research vessel, CCGC *PANDALUS III*. Weekly samples were collected from early May to the end of September or October, depending on the decline of the fall phytoplankton blooms. Biweekly sampling was conducted in the shoulder bloom months such as April and October (when phytoplankton cell densities had begun to increase or decrease) and monthly during all other colder months.

Phytoplankton samples were collected at the surface by bucket from all five stations, and at depths of 10 m, 25 m, and 50 m with a Niskin bottle at Station 16. Water samples (250 mL) were immediately preserved with 5 mL formaldehyde:acetic acid. Later, 50-mL subsamples were settled in counting chambers for 16 h. Phytoplankton greater than 5 µm were identified and enumerated (as cells•L^{-1}) with the Utermöhl technique using a Nikon inverted microscope (Sournia 1978).

Following analyses for phytoplankton abundance and distribution, the results were entered into a Microsoft Access database with the following fields: survey type, sampling station, date, organism (species name), code ("1" – dinoflagellate, "2" – diatom and "3" other which included ciliates and smaller zooplankton), and depth (only surface samples were used for this report although samples were collected at other depths at selected sites). Counts for cells were recorded as cells•L^{-1}. The dataset was used to generate a time-series of the near surface abundance of *D. brightwellii* for each of the five primary sampling stations. Data was retrieved from Access using queries for the first occurrence, maximum occurrence, etc., and copied into an Excel spreadsheet for sorting and data manipulation. Three point running medians and logarithms were calculated using Excel. Data were then imported into SigmaPlot (2001) for plotting. SigmaPlot

was used for plotting time series versus abundance, 3 point running medians and bubble plots for each station. Lattice plots showing annual first appearance versus year, date of maximum occurrence versus year, length of maximum bloom versus year and maximum concentration versus year were created using "R" (v. 2.4.0): A Programming Environment for Data Analysis and Graphics (R Development Core Team 2007).

Data from phytoplankton analyses of the total community for 1987- 2000 have been previously published (Wildish et al. 1990; Martin et al. 1995, 1999, 2001b, 2006b); the data from 2001-04 is not as yet published (J.L. Martin, Biological Station, 531 Brandy Cove Road, St. Andrews, NB E5B 2L9, pers. commun.).

RESULTS

The number of sample days for each station for each year from 1987- 2004 shows that sample days varied between the stations from 177 days at Station 25 to 513 days at Station 3 (Table 1).

Table 1. Number of sampling days/station for each year from 1987-2004. n/a means that samples were not collected.

Year	Station 3 Lime Kiln Bay	Station 15 Deadmans Harbour	Station 16 The Wolves Islands	Station 17 Brandy Cove	Station 25 Passamaquoddy Bay
1987	20	n/a	n/a	n/a	n/a
1988	28	23	25	25	n/a
1989	31	30	25	31	n/a
1990	31	28	25	29	n/a
1991	32	32	22	32	n/a
1992	29	29	24	29	n/a
1993	29	29	26	29	n/a
1994	27	27	19	27	n/a
1995	27	27	27	27	n/a
1996	25	24	22	24	n/a
1997	25	26	23	24	n/a
1998	29	28	27	29	n/a
1999	29	28	28	29	26
2000	29	30	31	31	31
2001	30	30	30	31	31
2002	28	25	24	27	26
2003	33	33	30	33	32
2004	31	31	31	31	31
Total	513	480	439	488	177

Variables, such as the fact that sampling occurred only at Station 3 in 1987 and the first part of 1988, resulted in the higher number of sample days at that particular location. Station 17 was sampled on a regular basis once sampling was initiated due to its easy access and close proximity to the Biological Station. Very occasionally it was not possible to sample Station 15 due to weather or the fact that the harbour was shut off for herring fishing. Sampling at Station

16 was occasionally affected by weather or sea conditions either unsafe or not conducive for sampling. Sampling at Station 25 was initiated in 1999.

Figures 3, 4, 5, 6 and 7 show cell densities of *D. brightwellii* from 1987 to 2004 on both log and linear scales from Lime Kiln Bay (Station 3), Deadmans Harbour (Station 15), the Wolves Islands (Station 16), Brandy Cove (Station 17) and mid-Passamaquoddy Bay (Station 25), respectively. *D. brightwellii* was detected at very low densities (<600 cells•L^{-1}) with the exception of 1990 at Station 16 (almost 25,000 cells•L^{-1}) prior to 1993 during the study period. Starting in 1994 and ending in 1999, counts approached 10 000 – 20 000 cells•L^{-1} at 3 stations (the Wolves Islands, Deadmans Harbour and Lime Kiln Bay). The densities continued to rise until 2003 when most stations reached their maximum counts.

Table 2 and Fig. 9 show the *D. brightwellii* maximum cell densities observed during each year at each of the 5 stations. During 2002 (Passamaquoddy Bay) and 2003 (east of Letete Passage), concentrations were significantly higher at all stations, with the Wolves Islands site having a maximum cell density >1.86 x 10^5 cells•L^{-1}. The following year (2004) densities were again similar to those observed prior to 1994, with the highest density (4913 cells•L^{-1}) observed at Passamaquoddy Bay at Station 25. Greatest abundances were observed at Stations 3 (1.52 x 10^5cells•L^{-1}), 15 (9.88 x 10^4 cells•L^{-1}) and 16 (1.87 x 10^5 cells•L^{-1}) in 2003, whereas the highest densities for stations 17 (1.2 x 10^4 cells•L^{-1}) and 25 (1.6 x 10^4 cells•L^{-1}), were observed in 2002.

Table 2. Maximum *D. brightwellii* cell densities (in cells•L^{-1}) from 1987-2004 at Stations 3, 15, 16, 17 and 25. Shaded numbers indicate maximum cell density for a particular station over the time series. n/a means that samples were not collected.

Year	Station 3 Lime Kiln Bay	Station 15 Deadmans Harbour	Station 16 The Wolves Islands	Station 17 Brandy Cove	Station 25 Passamaquoddy Bay
1987	160	n/a	n/a	n/a	n/a
1988	80	20	60	20	n/a
1989	240	300	420	40	n/a
1990	7 200	6 320	23 120	120	n/a
1991	60	140	80	40	n/a
1992	80	160	560	40	n/a
1993	40	60	160	60	n/a
1994	16 240	11 120	7 600	1 660	n/a
1995	7 680	6 200	6 640	360	n/a
1996	960	960	500	180	n/a
1997	12 760	18 370	10 200	1 720	n/a
1998	2 240	2 400	4 440	2 120	n/a
1999	30 720	33 440	16 880	2 400	3 680
2000	3 120	9 440	29 200	160	280
2001	12 080	22 080	35 840	384	400
2002	5 840	4 624	5 120	**11 840**	**16 064**
2003	**152 014**	**98 838**	**186 670**	5 597	10 808
2004	680	504	560	200	4 913

A bloom event for *D. brightwellii* is characterized as an event where *D. brightwellii* cells are detected in the water, or an unbroken sequence of two or more samples with *D. brightwellii* present. Fig. 8 shows bubble plots indicating the presence and bloom duration of *D. brightwellii* at the five stations since 1987. The size of the circle reflects the number of cells observed – the larger the circle, the larger the bloom or concentration of cells. It shows that cells are observed in low concentrations prior to day 200 (mid July) but can often persist at least until day 300 (late October). Generally, the bloom with the highest cell density occurs in the fall between days 225-275, in August or September (Table 3, Fig. 10). Highest concentrations for the five stations during the sampling period were observed during the months of September for Stations 3, 15, and 16 and August at Stations 17 and 25.

Table 3. Month of the year where the maximum cell concentration of *D. brightwellii* occurred at the five stations: 3 (Lime Kiln Bay), 15 (Deadmans Harbour), 16 (the Wolves Islands), 17(Brandy Cove)and 25 (Passamaquoddy Bay). Shaded months indicate years of maximum cell density during the sampling period for a particular station. n/a means samples were not collected.

Year	Station 3	Station 15	Station 16	Station 17	Station 25
1987	September	n/a	n/a	n/a	n/a
1988	December	October	December	October	n/a
1989	September	September	September	September	n/a
1990	September	September	September	September	n/a
1991	October	October	July	June	n/a
1992	July	July	August	August	n/a
1993	August	October	July	November	n/a
1994	September	September	August	September	n/a
1995	September	September	September	September	n/a
1996	August	August	October	August	n/a
1997	September	September	September	November	n/a
1998	October	October	October	October	n/a
1999	August	August	August	August	September
2000	September	October	September	September	November
2001	September	September	September	August	December
2002	August	September	August	**August**	**August**
2003	**September**	**September**	**September**	September	September
2004	October	September	October	November	October

The duration for the bloom events that had the maximum cell densities for *D. brightwellii* for each year varied from 1-394 d (Table 4, Fig. 11). The bloom with the longest duration (394 d) occurred in 1994-1995 at Station 15. The bloom with the next longest length (372 d) occurred at Station 16 of the same years, whereas maximum bloom lengths for Stations 3, 17 and 25 were 310 (1996), 279 (1994) and 260 (1999), respectively. Interestingly, none of the stations had their maximum bloom concentration occur in the same year as their longest bloom duration.

Table 4. Length (in days) of the maximum bloom for each station in each year. Shaded numbers indicate the longest bloom period for a given station during the study period. n/a means that samples were not collected.

Year	Station 3 Lime Kiln Bay	Station 15 Deadmans Harbour	Station 16 The Wolves Islands	Station 17 Brandy Cove	Station 25 Passamaquoddy Bay
1987	41	n/a	n/a	n/a	n/a
1988	1	48	78	28	n/a
1989	62	97	159	21	n/a
1990	135	99	84	99	n/a
1991	43	14	7	1	n/a
1992	28	1	27	27	n/a
1993	1	106	15	25	n/a
1994	279	**394**	**372**	**279**	n/a
1995	154	314	314	124	n/a
1996	**310**	153	310	161	n/a
1997	112	15	126	154	n/a
1998	289	310	219	261	n/a
1999	162	245	344	181	**260**
2000	277	198	226	190	232
2001	55	27	247	155	43
2002	119	175	119	210	168
2003	190	197	34	41	183
2004	105	84	91	91	91

The date of first occurrence for *D. brightwellii* was fairly consistent between stations (Table 5, Fig. 12) and ranged from Day 1 (January 1) to Day 249 (September 6). It tended to occur earlier in the Passamaquoddy Bay station (25) than in the offshore and exposed sites. The mean day of the first occurrence ranged from Day 35-90 (February 4 – March 31) and the median day ranged from 19-64.5 (January 19 - March 5 or 6).

Table 5. Ranges of days for first occurrences of *D. brightwellii*, including mean and median days of occurrences for the five stations.

	Station 3 Lime Kiln Bay	Station 15 Deadmans Harbour	Station 16 Wolves Islands	Station 17 Brandy Cove	Station 25 Passamaquoddy Bay
Range for 1st occurrence	2 - 229	6 - 249	6 - 229	6 - 249	6 - 119
Mean	66	68	90	66	35
Median	25	31.5	64.5	20	19

Further information on the description of the blooms of *D. brightwellii* indicate that the median day of the maximum cell abundance ranged from day 249 – day 268 or from September 6 – September 25 (Table 6). Median duration of the blooms ranged from 106d – 175.5d; and the median maximum cell abundance ranged from 200-5120 cells•L^{-1}. The mean annual duration of

the presence of *D. brightwellii* for each station ranged from 93d-151d (occurring from June to December) and had a mean of 129d.

Table 6. Summary of descriptive analyses from data on *D. brightwellii* including: median day of first occurrence, median day of maximum cell abundance, median duration in days of the bloom with the greatest cell abundance, median of the maximum cell abundance for all years, and the mean for the annual duration of the presence of cells.

Variable (units)	Station 3 Lime Kiln Bay	Station 15 Deadmans Harbour	Station 16 Wolves Islands	Station 17 Brandy Cove	Station 25 Passamaquoddy Bay
Median day of first appearance (Day of Year)	25	31.5	64.5	20	19
	Jan 25	Jan 31 or Feb 1	Mar 5 or 6	Jan 20	Jan 19
Median day of maximum cell abundance (Day of Year)	260.5	265	258	249	268
	Sep 17 or 18	Sep 22	Sep 15	Sep 6	Sep 25
Median maximum bloom duration (days)	115.5	106	126	124	175.5
Median maximum cell abundance (cells·L-1)	2 680	4 624	5 120	200	4 296.5
Mean annual duration (days)	122	125	151	140	93

DISCUSSION

The phytoplankton monitoring program was initiated in 1987 following concerns that the local salmon industry might experience problems that were happening elsewhere in the world where the industry has been established for a longer period. Although more than 48 species of dinoflagellates, 94 species of diatoms and 21 other species (including smaller zooplankton and ciliates), have been observed from the region (Wildish et al. 1990; Martin et al. 1995, 1999, 2001b, 2006b); the data from 2001-04 is not as yet published (J.L. Martin, Biological Station, 531 Brandy Cove Road, St. Andrews, NB E5B 2L9, pers. commun.), the majority do not cause harm. Results from monitoring of phytoplankton cell densities from 1987-2004 show that occurrences of phytoplankton species have seasonal, inter-annual and decadal variations in abundances, and all species in the Bay of Fundy behave differently. Earlier analyses of *A. fundyense* populations further emphasize this variation (Page et al. 2004, 2005, 2006).

D. brightwellii was observed in the Bay of Fundy in the early 1930s and is therefore not a new species to the area (Gran and Braarud 1935). Their records indicate that: during 1931 and 1932 it was observed from March to September; it was most abundant in August-September;

maximum cell densities were 1420 cells•L^{-1} in September 1931 and 1000 in August 1932, and it was most abundant offshore around Grand Manan Island. This is consistent with the present analysis which shows highest concentrations in the offshore area and the most abundant periods being August and September. Our study revealed that *D. brightwellii* was observed at very low cell densities (<1000 cells•L^{-1}) at all of our sampling sites prior to 1990, from 1991 to 1993 and in 1996. It is a very distinct (and relatively large) species, so it would not have been easily missed during either our counts or earlier counts by Gran and Braarud (1935). As the appearances and abundances of *D. brightwellii* appear to vary greatly between years, and the study in the early 1930's was only for a 2-yr period, we do not know whether there have been periods of higher cell density in the interim. It was interesting to see that in 2003 for Stations 3, 15 and 16, cell concentrations were almost five times higher than previously observed. In 2002, for Stations 17 and 25, they were almost twice as much as previously observed.

The highest concentrations (1.87×10^5 cells•L^{-1}, 1.52×10^5 cells•L^{-1} and 9.88×10^4 cells·L^{-1}) were in 2003 at the Wolves Islands, Lime Kiln Bay and Deadmans Harbour, respectively, in areas east of Letete Passage and influenced by the offshore Bay of Fundy. The more inshore areas, mid-Passamaquoddy Bay and Brandy Cove, had much lower concentrations at 1.6×10^4 cells·L^{-1} and 1.2×10^4 cells·L^{-1}, respectively, and these occurred in 2002. Analyses from the study period suggest that the Passamaquoddy Bay region was less conducive to the higher cell densities and blooms of *D. brightwellii*. The inshore area has more freshwater influence, shallower water, and less mixing and flushing. Additionally, conditions in 2003 must have been more conducive to blooms of *D. brightwellii* as the highest concentrations were observed during those years. The high cell densities in that year were the highest recorded in the 18 yr of the phytoplankton monitoring program. These high numbers coincided with problems associated with salmon farms in the Grand Manan Island area when high concentrations of *A. fundyense* were linked to fish mortalites (Martin 2006a; J.L. Martin, Biological Station, 531 Brandy Cove Road, St. Andrews, NB E5B 2L9, unpublished data). These observations suggest that if concentrations reach levels that were detected in 2003, there might be problems with salmon farmed in the area. Further exposure of Atlantic salmon to *D. brightwellii* under laboratory conditions would also need to be conducted as preliminary initial experiments exposing salmon to high concentrations of *D. brightwellii* (1.0×10^6 cells•L^{-1}) for 24 h did not result in fish mortalities (Les E. Burridge, Biological Station, 531 Brandy Cove Road, St. Andrews, NB E5B 2L9, pers. commun.).

This synthesis provides information on the patterns and trends of populations of *D. brightwellii* from 1987-2004 in the southwestern New Brunswick region of the Bay of Fundy area. It is an initial phase of analysis of the data and the first documentation of the trends for this particular species from the Fundy region. This phytoplankton monitoring program is ongoing, with additional data being collected each year. Continued studies with this valuable long time series and analyses of the phytoplankton data in association with related physical, chemical and environmental data will aid and further improve our predictive/hindcasting capabilities and the search for relationships between the linkages and variables influencing the blooms.

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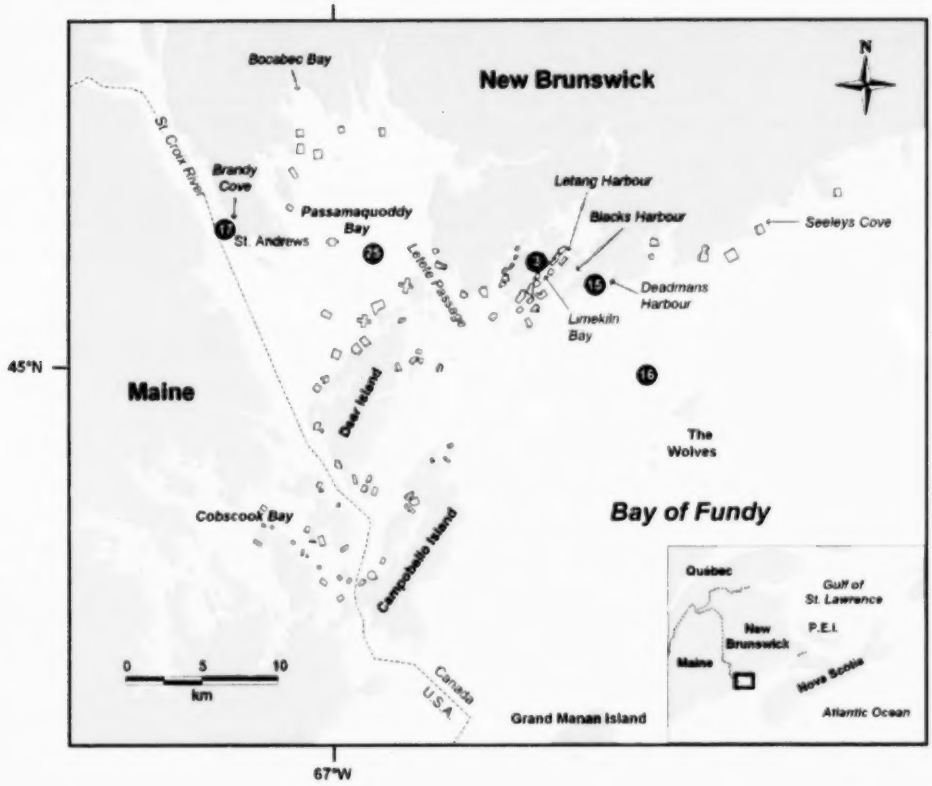

Fig. 1. Map showing sampling stations Brandy Cove (Station17), Lime Kiln Bay (Station 3), Deadmans Harbour (Station 15), the Wolves Islands (Station 16) and mid-Passamaquoddy Bay (Station 25). Assorted shapes indicate locations of salmon aquaculture sites.

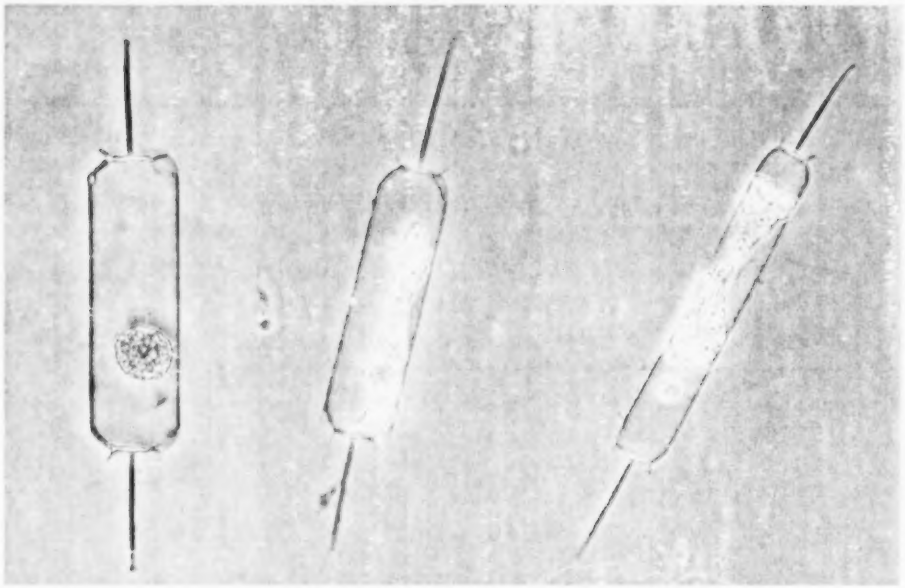

Fig. 2. *D. brightwellii* from the Bay of Fundy.

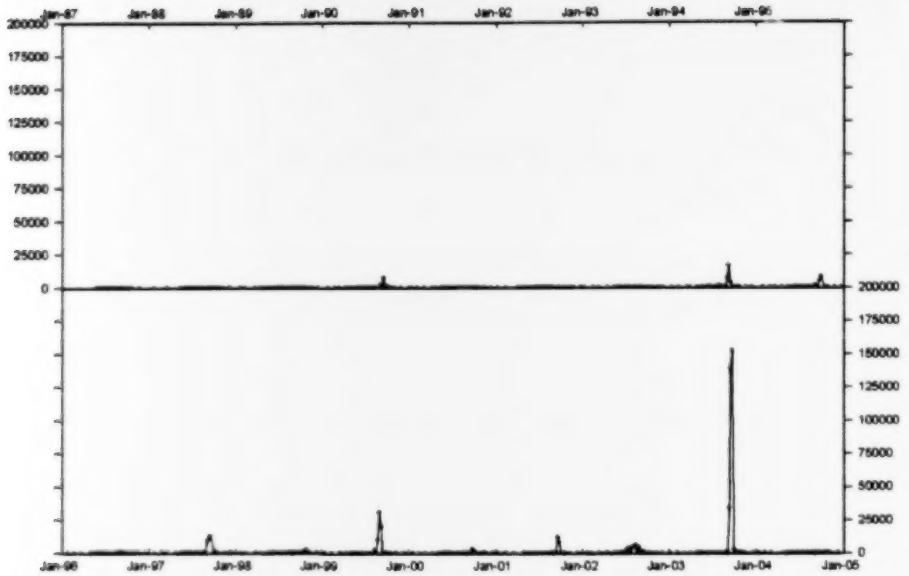

Fig. 3A. Concentrations (cells·L^{-1}) of *D. brightwellii* from Lime Kiln Bay (Station 3) from 1987-2004 on a linear scale. Upper portions of figures are the 9 yr 1987-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100 000 cells•L^{-1} concentration.

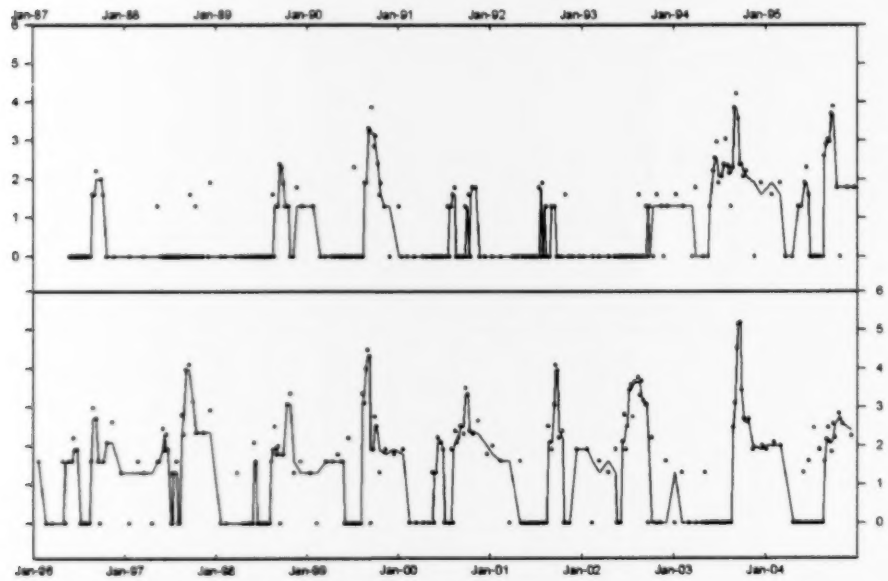

Fig. 3B. Concentrations (cells·L^{-1}) of *D. brightwellii* from Lime Kiln Bay (Station 3) from 1987-2004 on a log-transformed scale. Upper portions of figures are the 9 yr 1987-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100 000 cells•L^{-1} concentration.

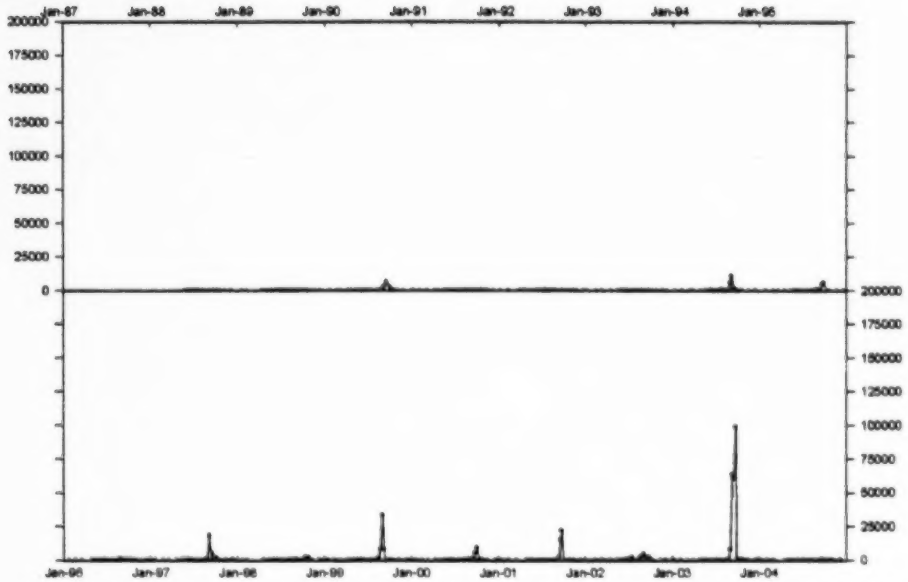

Fig. 4A. Concentrations (cells•L^{-1}) of *D. brightwellii* from Deadmans Harbour (Station15) from 1988-2004 on a linear scale. Upper portions of figures are the 8 yr 1988-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100 000 cells•L^{-1} concentration.

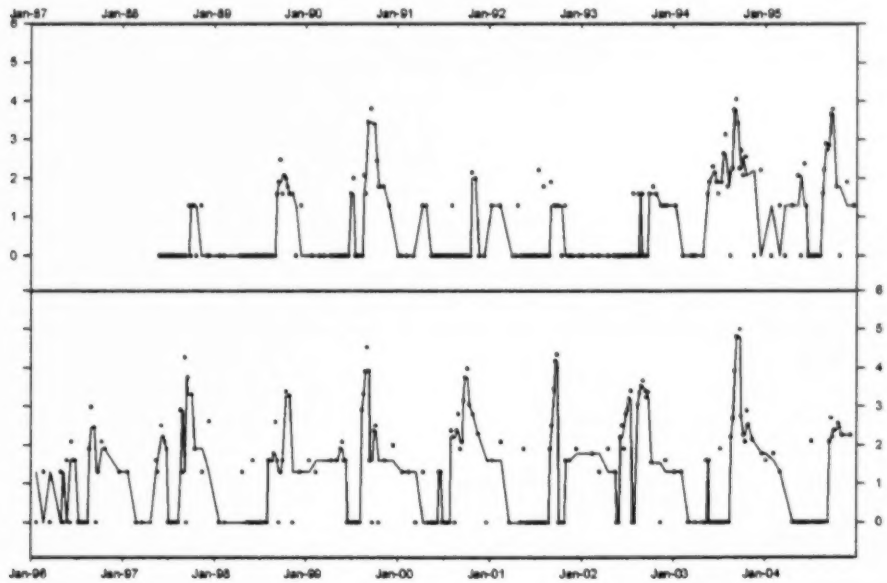

Fig. 4B. Concentrations (cells•L^{-1}) of *D. brightwellii* from Deadmans Harbour (Station15) from 1988-2004 on a log-transformed scale. Upper portions of figures are the 8 yr 1988-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100 000 cells•L^{-1} concentration.

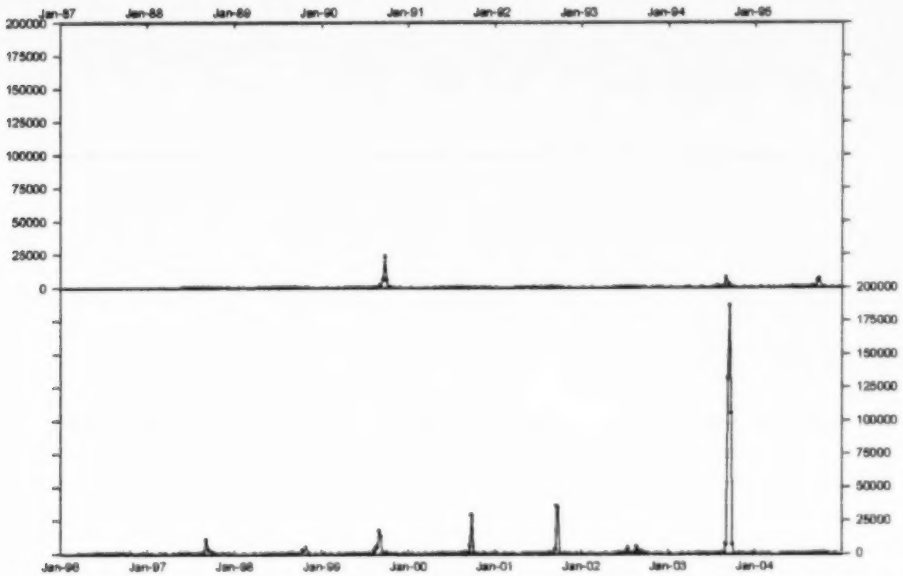

Fig. 5A. Concentrations (cells•L^{-1}) of *D. brightwellii* from the Wolves Islands (Station16) from 1988-2004 on a linear scale. Upper portions of figures are the 8 yr 1988-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100 000 cells•L^{-1} concentration.

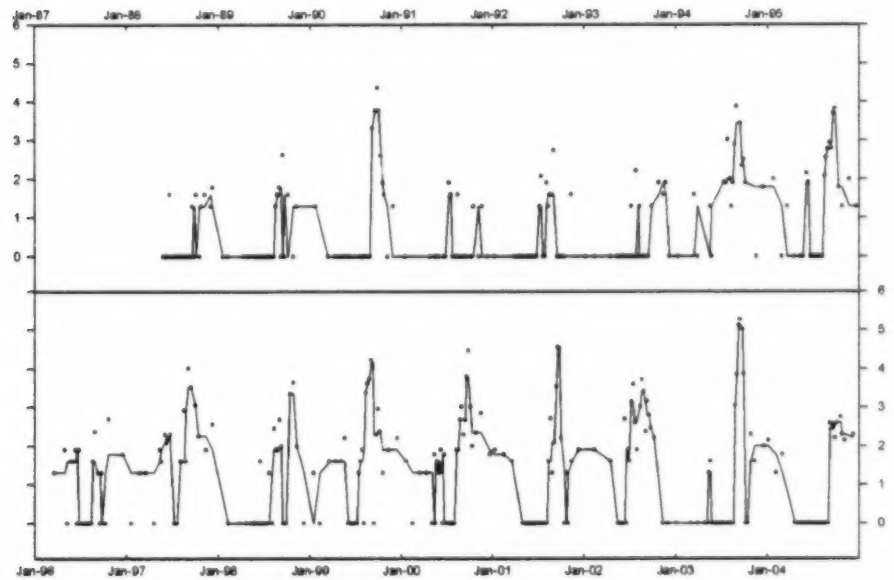

Fig. 5B. Concentrations (cells•L^{-1}) of *D. brightwellii* from the Wolves Islands (Station16) from 1988-2004 on a log-transformed scale. Upper portions of figures are the 8 yr 1988-95 and the lower portions are the 8 yr 1996-2004. Dotted line indicates the 100 000 cells•L^{-1} concentration.

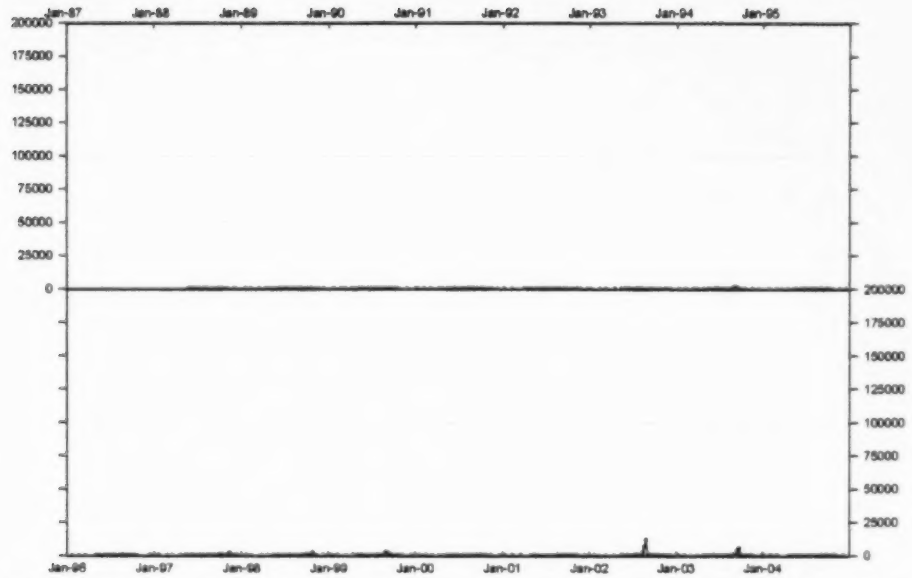

Fig. 6A. Concentrations (cells•L^{-1}) of *D. brightwellii* from the Brandy Cove (Station 17) from 1988-2004 on a linear scale. Upper portions of figures are the 8 yr 1988-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100 000 cells•L^{-1} concentration.

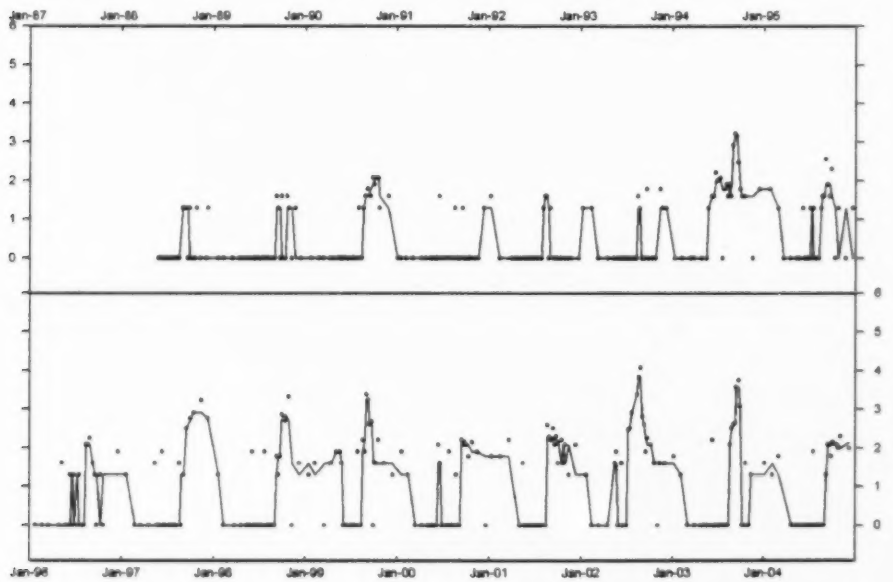

Fig. 6B. Concentrations (cells•L^{-1}) of *D. brightwellii* from Brandy Cove (Station 17) from 1988-2004 on a log-transformed scale. Upper portions of figures are the 8 yr 1988-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100 000 cells•L^{-1} concentration.

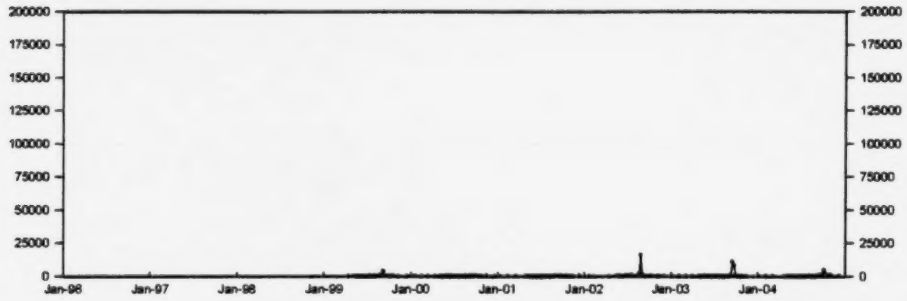

Fig. 7A. Concentrations (cells•L^{-1}) of *D. brightwellii* from mid-Passamaquoddy Bay (Station 25) on a linear scale (1999-2004). Dotted line indicates the 100 000 cells•L^{-1} concentration.

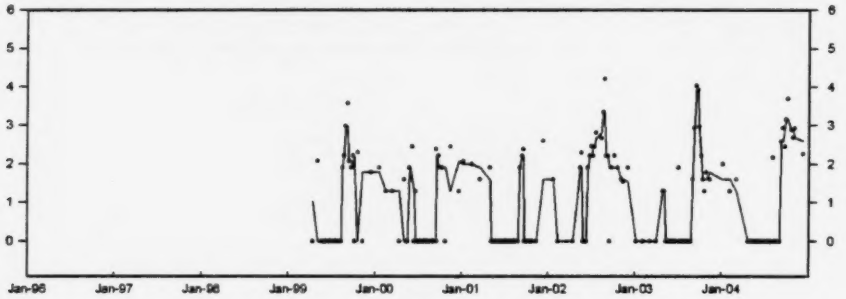

Fig. 7B. Concentrations (cells•L^{-1}) of *D. brightwellii* from mid-Passamaquoddy Bay (Station 25) on a log-transformed scale (1999-2004). Dotted line indicates the 100 000 cells•L^{-1} concentration.

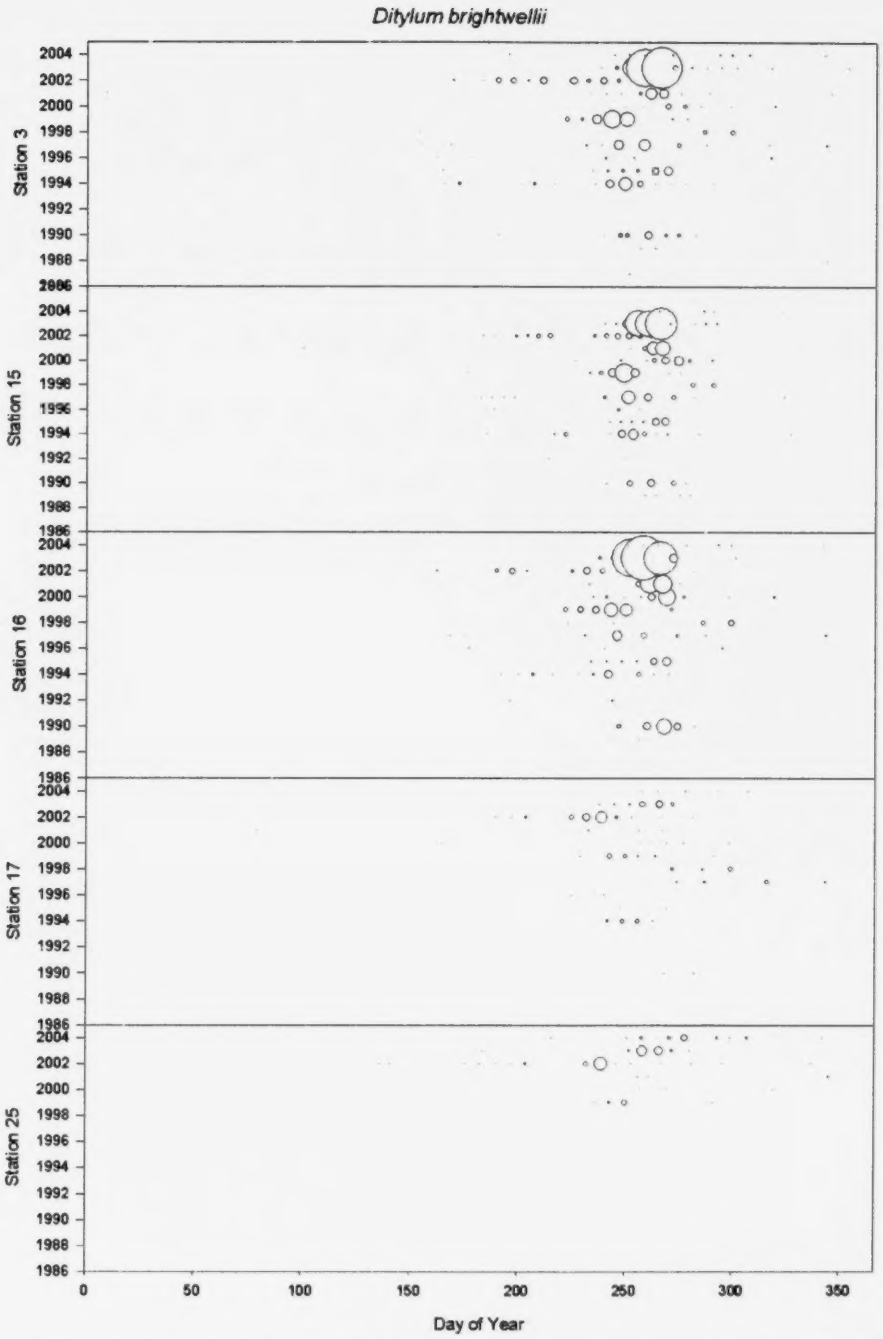

Fig. 8. Bubble graphs showing the *D. brightwellii* bloom durations from 1987-2004. Size of the circles indicates the cell concentrations (cells•L^{-1}). Station #25 was not sampled prior to 1999.

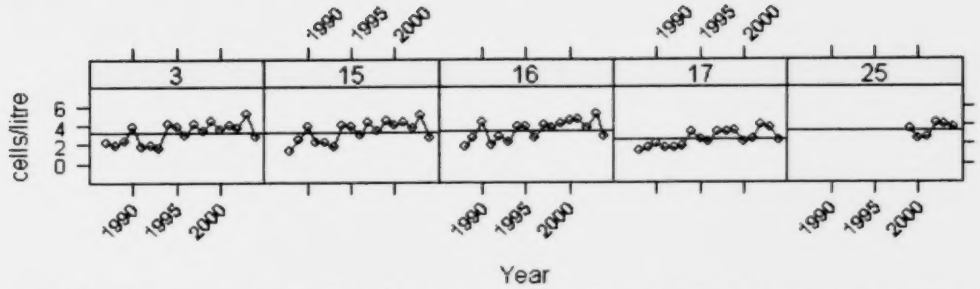

Fig. 9. Maximum density (cells•L^{-1}) of *D. brightwellii* at Stations 3, 15, 16, 17, and 27 on a log-transformed scale. Solid line indicates the mean of the log cell concentrations.

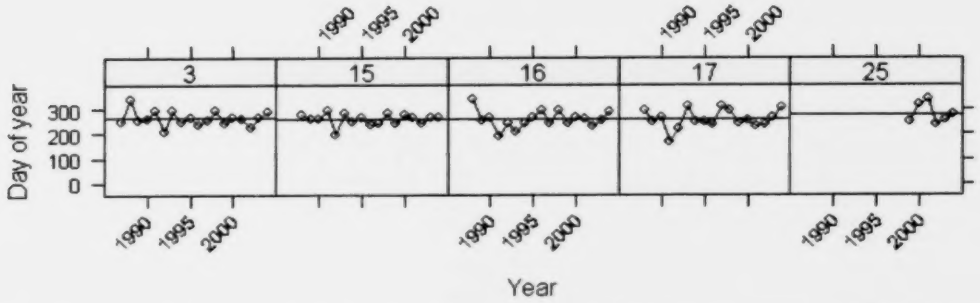

Fig. 10. Day of the year that the maximum cell density was observed. Solid line indicates the mean.

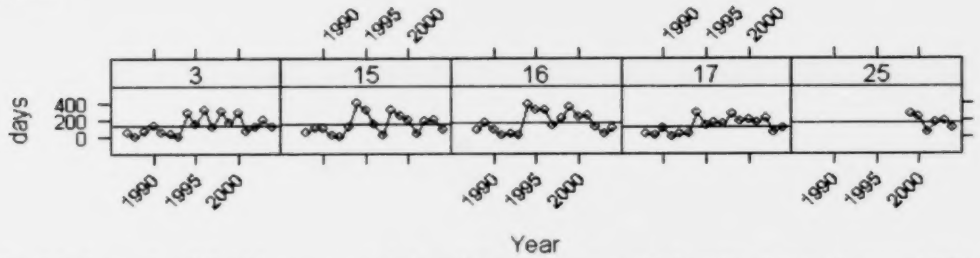

Fig. 11. Length of the bloom containing the maximum cell density for each year 1987-2004.

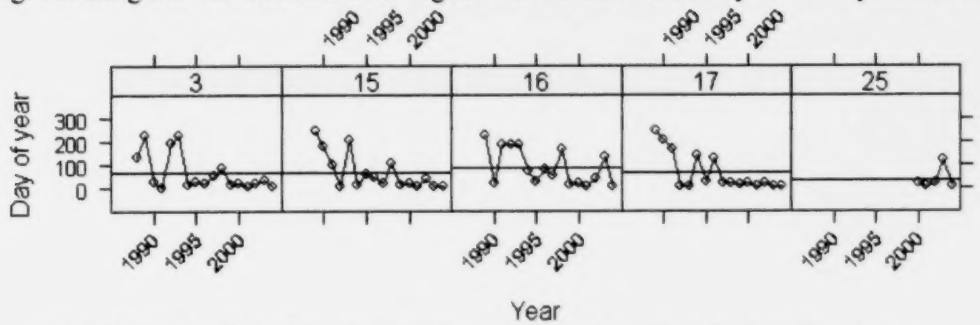

Fig. 12. Date of the first appearance of *D. brightwellii* cells in a given year.